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Potential for Utilizing POME to Produce Biohydrogen Gas Using Microbial Electrolysis Cell

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ABSTRACT

Palm oil mill effluent contains organic matter and microorganisms that can potentially be reused despite of its impact to the environment. Microbial electrolysis cell is a method that utilizes electrogenic bacteria to produce hydrogen gas. This study aims to explore the potential for utilizing palm oil mill effluent to produce hydrogen gas using microbial electrolysis cells. Experiments were conducted in a specially built MEC reactor with a 3.5 L capacity with 0.5, 1.0, and 1.5 V with carbon fiber cloth as electrodes. A gas analyzer was used to measure hydrogen gas over the course of 24 h at a 2 h interval. Palm oil mill effluent was utilized as a substrate, while distilled water was used as a control. Experiments demonstrate that the amount of hydrogen gas produced increases as the voltage increases, with values of 37 mg m^{-3} at 0.5 V, 136 mg m^{-3} at 1.0 V, and 358 mg m^{-3} at 1.5 V. When comparing the yield of hydrogen gas produced with distilled water substrate at 1.5 V, the yield of palm oil mill effluent substrate is always higher. This could be due to microbial activity increasing the rate of electrolysis of the substrate into hydrogen gas.

Key words: *carbon fiber cloth, DC voltage, MEC, palm oil mill effluent*

INTRODUCTION

Hydrogen, with its high energy content while being ecologically safe, is one of the most promising alternative fuels for the future. Because the end result of combustion hydrogen gas are water and heat, hydrogen is a clean and carbon-free fuel (Ghimire *et al.* 2015). Hydrogen is the most abundant element and is found in air and organic compounds. The energy content of hydrogen at a higher heating value is 141.8 MJ kg^{-1} at 298 K and 120 MJ kg^{-1} at 298 K at a lower heating value. This value is higher than most other fuels; for example, gasoline has only 44 MJ kg^{-1} of energy at 298 K (Dawood *et al.* 2019).

The use of hydrogen as an alternative energy has challenges in terms of its production. Hydrogen in commercial applications comes mostly from natural gas

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and oil. The hydrogen production process still has drawbacks, such as a high energy requirement and the use of non-renewable energy sources. The use of biological processes to produce hydrogen is more environmentally friendly because it uses less energy and can utilize waste biomass. The microbial electrolysis cell (MEC) method is one of several methods for producing biohydrogen (Ghimire *et al.* 2015).

Microbial electrolysis cells are bio-electrochemical systems (BESs) where voltage is required to create bio-electrochemical reactions (Liu *et al.* 2010). The combination of "bio" (electrolysis of bacteria from organic matter) and "electrochemical" (addition of voltage) makes it possible to produce hydrogen gas in the MEC process (Varanasi *et al.* 2019). MEC technology evolved from a microbial fuel cell (MFC), which is a technology for producing hydrogen and treating organic waste at the same time (Dai *et al.* 2019). In MEC, active microbes grow around the anode and break down organic matter into CO_2, electrons, and protons. At the cathode, the released electrons combine with protons to form hydrogen gas. There are several factors that effect the MEC process, namely pH, temperature, applied voltage, and substrate (Liu *et al.* 2010).

The substrate aids in the donation to electrogenic bacteria, which oxidize the substrate and transfer electrons to the cathode via the anode to produce hydrogen gas (Varanasi *et al.* 2019). Almost all organic substrates can be used in MEC ranging from simple carbohydrates to complex fermentable substrates such as biomass and wastewater (Kadier *et al.* 2016). Palm oil mill effluent (POME) is waste from palm oil processing which can be pollute the environment if it is not processed first. POME has a high organic matter content and is a liquid waste with a high level of pollution. This can be seen from the physicochemical characteristics of POME such as high BOD, COD, and TSS values of 37,750 mg L^{-1}, 69,500 mg L^{-1}, and 47,690 mg L^{-1} (Norfadilah *et al.* 2016). According to Nitipan *et al.* (2014), POME contains microorganisms that play a role in the production of biohydrogen, one of which is *Clostridium thermocellum* which is capable of producing acetate and hydrogen.

Microbial electrolysis cells are one of method to produce hydrogen gas. The potential for utilizing POME by MEC system in Indonesia has not yet been carried out. The applied voltage is one of the factors that influences the MEC process results. In addition, there is a monitoring system in the bioreactor so that changes that occur during the reaction can be monitored. Therefore, this study aims to explore the potential for utilizing POME by microbial electrolysis cell to produce hydrogen gas.

MATERIALS AND METHODS

The bioreactor used was designed by a team, with a design as shown in Figure 1. The bioreactor used is a single chamber type made of acrylic with an outer diameter of 15 cm and an inner diameter of 14 cm, and a height of 27 cm. The electrodes used are 3K Twill 2x2 220 gsm carbon fiber cloth with dimensions of 17 x 50 cm.

The voltage is given using a DC power supply (Wanptek DPS3010U). To monitor temperature, pH, and electrical conductivity, sensors are used with their respective specifications, namely: DS18b20, Dfrobot pH Sensor, Dfrobot EC Sensor V2, and Arduino UNO as a microcontroller. POME was obtained from PTPN VIII Cikasungka

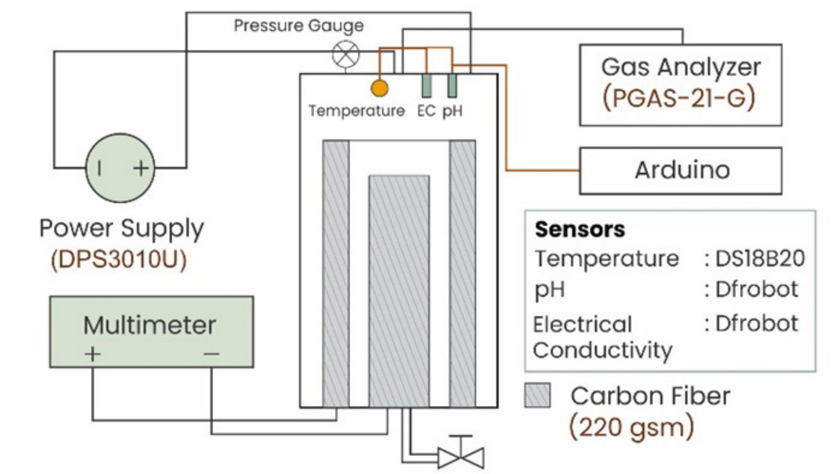


Figure 1 Bioreactor system.

Bogor in waste pond 1 with one collection. There is no addition of microbes to the substrate. Before the process starts, POME is put into cold storage.

Method of Collecting Data

The research begins with the preparation of tools and the design of the bioreactor. The bioreactor with a capacity of 3.5 L is designed to be able to accommodate the hydrogen gas produced. The next stage is taking POME from PTPN VIII, Cikasungka Bogor. POME is then given pre-treatment, which is put in a cold room until the temperature reaches 4 ^{o}C and then heated to 30 ^{o}C when it is used. The treatment with a difference of 0.5, 1.0, and 1.5 V was carried out for 24 h with 2 h intervals and two repetitions. The gas produced will be measured using a gas analyzer (PGAS-21-G) with a flow rate of 0.7 L min^{-1}. The bioreactor is equipped with a monitoring system that includes temperature, pH, and EC with five seconds measurement intervals.

RESULT AND DISCUSSION

Characterisstics of Palm Oil Mill Effluent

POME has characteristic organic content which is expressed in chemical oxygen demand (COD) which ranges from 50,000-200,000 mg L^{-1} and pH ranges from 4.0-4.5 which can be harmful to the environment if not treated first (Borja and Banks 1995). Industrial wastewater including POME is an essential habitat for a wide variety of microbes. Research conducted by (Bala *et al.* 2014) showed that there are various types of microbes that live in POME, ranging from gram-positive and negative bacteria, yeasts, to filamentous molds. The electrogenic bacteria isolated from POME plays a role in the MEC process (Table 1).

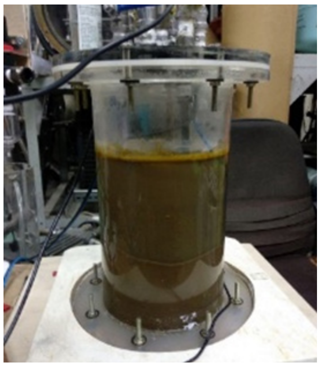
The Microbial Electrolysis Cell System Bioreactor

The MEC bioreactor has been successfully constructed as shown in Figure 2. The bioreactor is made of acrylic material and has a diameter of 14 mm, a height of 260 mm, and a thickness of 10 mm, allowing light to enter with an average light intensity of 100 lux at night and 456 lux at noon. The bioreactor's capacity is 3.5 L. The bioreactor has a monitoring system that measures temperature, pH of the EC, and H_2 gas. In addition, there is a power supply acting as a voltage source to regulate the delivered voltage.

Temperature, pH, and EC sensors will measure changes in temperature, acidity, and electrical conductivity every five seconds during the MEC process. There is a

Table 1 Isolation of bacteria on palm oil mill effluent

Bacterial Species	Function	Source
Micrococcus leuteus	Breaks down lipids into fatty acids and glycerol	(Bala *et al*. 2018)
Thermoanaerobacterium sp.	Produce hydrogen gas and butyric acid	(Mamimin *et al*. 2012)
Escherichia coli	Ferment sugar to lactic acid	(Ohimain *et al*. 2012)
Enterobacter cloacae	Producing hydrogen gas from carbohydrates and fatty acids	(Mun *et al.* 2008)
Clostridium thermocellum	Producing acetate and hydrogen	(Nitipan *et al.* 2014)
Methanobacterium sp.	Converting hydrogen to methane	(Poh *et al.* 2010)
Methanosaeta thermophila	Converting acetate to methane	(Tabatabaei *et al.* 2009)



a b

Figure 2 The microbial electrolysis cell system bioreactor: a. MEC Apparatus; b. bioreactor.

microcontroller (Arduino UNO) to read the sensor. All sensor readings will be stored directly on the laptop using the PLX-DAQ application. The voltage given from the power supply is adjusted until the voltage received by the electrode reaches 0.5, 1.0, and 1.5 V.

Several researchers applied carbon-based electrodes (Liu and Logan 2004; Call and Logan 2008; Liu *et al.* 2010). This is due to carbon's excellent electrical conductivity, biocompatibility, low overpotential, and low cost (Liu *et al.* 2010). As a result, carbon fiber was chosen as the electrode in this investigation. The carbon fiber used is 3K Twill 2x2 220 gsm carbon fiber with a length of 75 x 50 cm.

A gas analyzer is used to measure the amount of hydrogen gas in the bioreactor. The air in the bioreactor will be drawn out using the pump in the measuring equipment. The pump discharge rate is 0.7 L min^{-1}. The data reported by the measuring instrument is the level of hydrogen gas in mg m^3.

Palm oil mill effluent was treated before to the research by being stored in a cold room. The cooling process is carried out until the POME temperature is 4 ^{o}C. This is done to reduce microbial activity while POME is stored. Before Heating was carried out until POME temperature.

Biohydrogen Gas Potential

Figure 3 shows the results of measuring temperature, pH, EC, and H2 production at MEC with three parameters treatment, namely 0.5, 1.0, and 1.5 V. The result of pH measurement which is relatively stable at MEC is in accordance with the research of Khongkliang *et al.* (2019).

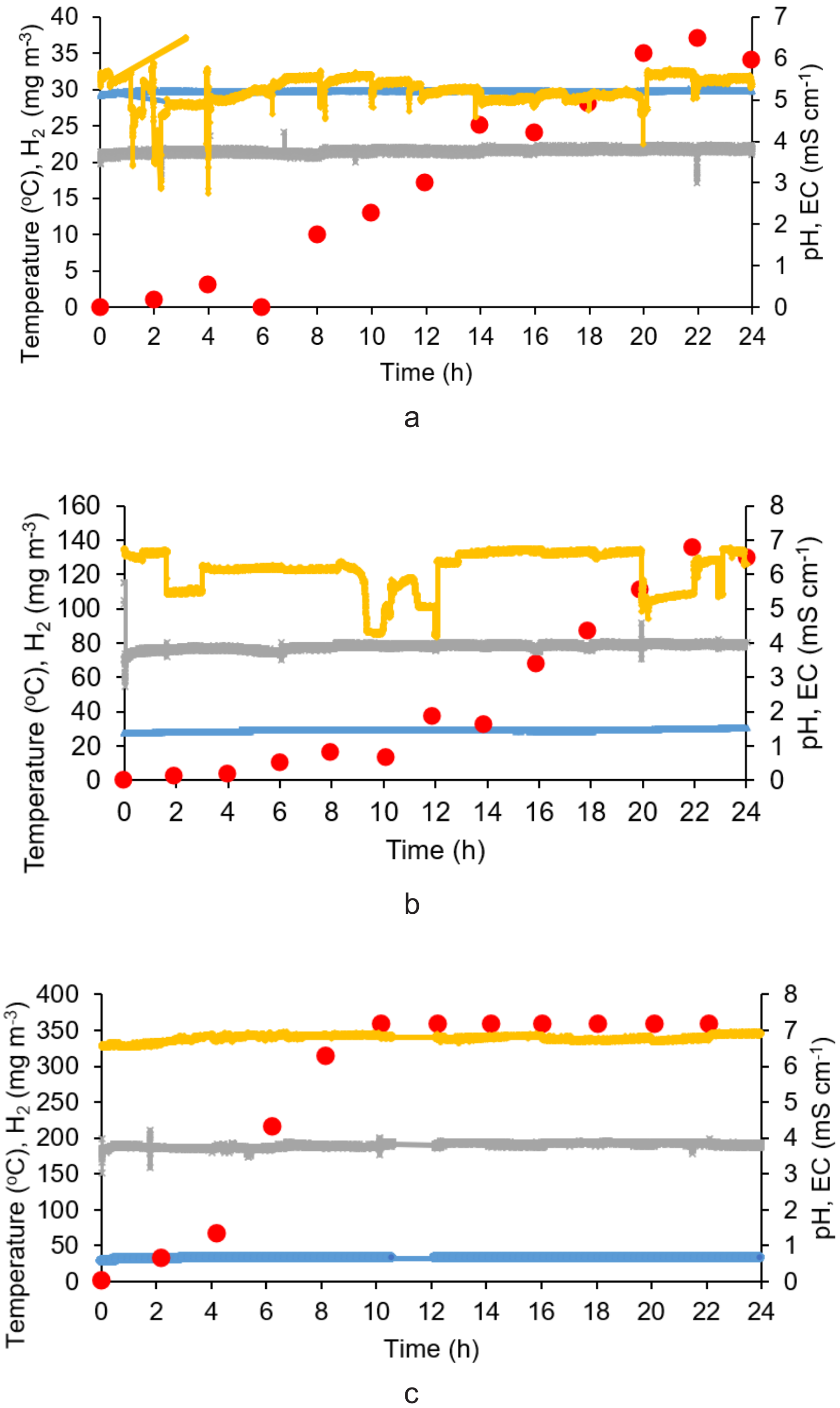


Figure 3 Correlation between temperature, pH, EC, and H_2 production at three voltages: a, 0.5 V, b, 1.0 V, and c, 1.5 V. Note: Y-axis scale is different. Temperature (°C) H_2(mg m^{-3}) pH EC (mS cm^{-1}).

The accumulation of volatile fatty acids (VFA) resulting from the fermentation process can lower the pH. However, there are bacteria that are able to convert VFA into hydrogen so that the pH value does not change significantly. Electrical conductivity is the ability of a liquid to conduct electricity and is closely related to the ion content contained in the liquid (Mandal 2014). Based on this, the fluctuating EC value is influenced by fluctuations in the ion content contained in the solution.

Table 2 presents data from the MEC process for several operating parameters at a voltage variation of 0.5, 1, and 1.5 V. The temperature recorded during the study was in the range of 27.94-32.31 °C with the maximum temperature indicated by a voltage of 1.5 V and the minimum temperature indicated by a voltage of 0.5 V. The degree of acidity varies between 2.69-5.35. The pH value tends to increase during the MEC process. The value of EC and current density is also directly proportional to the magnitude of the applied voltage. The POME density measured at the three voltages did not differ much because it came from the same source.

The greater the applied voltage, the greater the biohydrogen production obtained (Figure 4). This is in line with the research of Lim *et al.* (2020) which showed that from a given voltage experiment of 0.3-2.0 V, the optimum hydrogen production was observed at a voltage of 1.0 V. This could be due to the different activation energies of each bacterium. The optimum voltage in this study is 1.5 V. This voltage is the largest voltage tested in this study, so further research is needed with a higher voltage.

There is a comparison factor in the form of providing a voltage of 1.5 V in distilled water. The highest gas production is only 17 mg m^{-3}. This value is smaller than the POME substrate at the same voltage. This proves the influence of microbial activity in POME in producing hydrogen gas.

CONCLUSION

Based on the research that has been done there is an effect of voltage on the production of hydrogen gas. The production of biohydrogen is directly proportional to the applied voltage. The production obtained at a voltage of 0.5 V is 37 mg m^{-3} at a voltage of 1.0 V of 136 mg m^{-3}; and at 1.5 V of 358 mg m^{-3} and potentially higher. Comparison with hydrogen gas produced using distilled water as a substrate at a voltage of 1.5 V shows that the yield of POME substrate is always higher. These results indicate the potential for MEC utilization of POME for hydrogen production.

Table 2 Result of microbial electrolysis cell process

Parameter	Applied voltage (V)		
	0.5	1.0	1.5
H_2 concentration (mg m^{-3})	37.000	136.000	*358.000
Max temperature (°C)	30.060	30.940	32.310
Min temperature (°C)	27.940	28.190	28.560
Initial pH	3.670	3.670	3.670
Final pH	3.850	4.000	3.880
Electrical conductivity (mS cm^{-1})	5.240	6.640	6.730
POME density (kg L^{-1})	0.580	0.576	0.577
Current density (A cm^{-2})	3.650	7.058	11.880

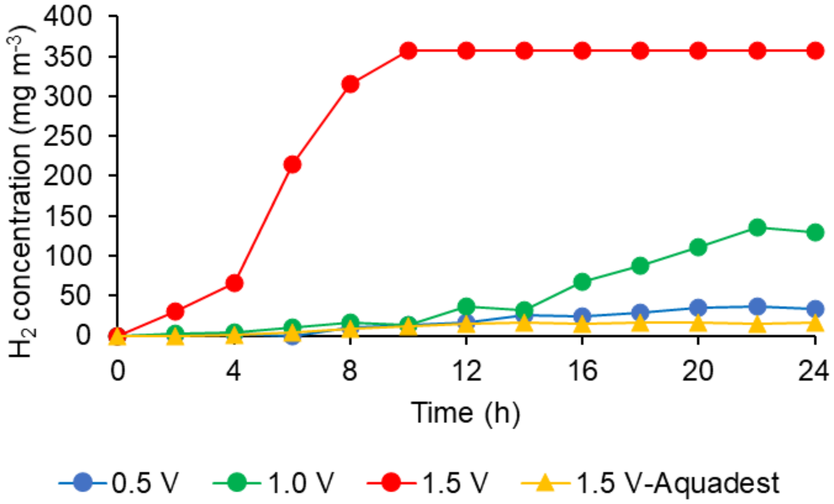


Figure 4 Applied voltage comparation to biohydrogen gas production.

This is thought to be the result of microbial activity in increasing the electrolysis of the substrate into hydrogen gas.

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